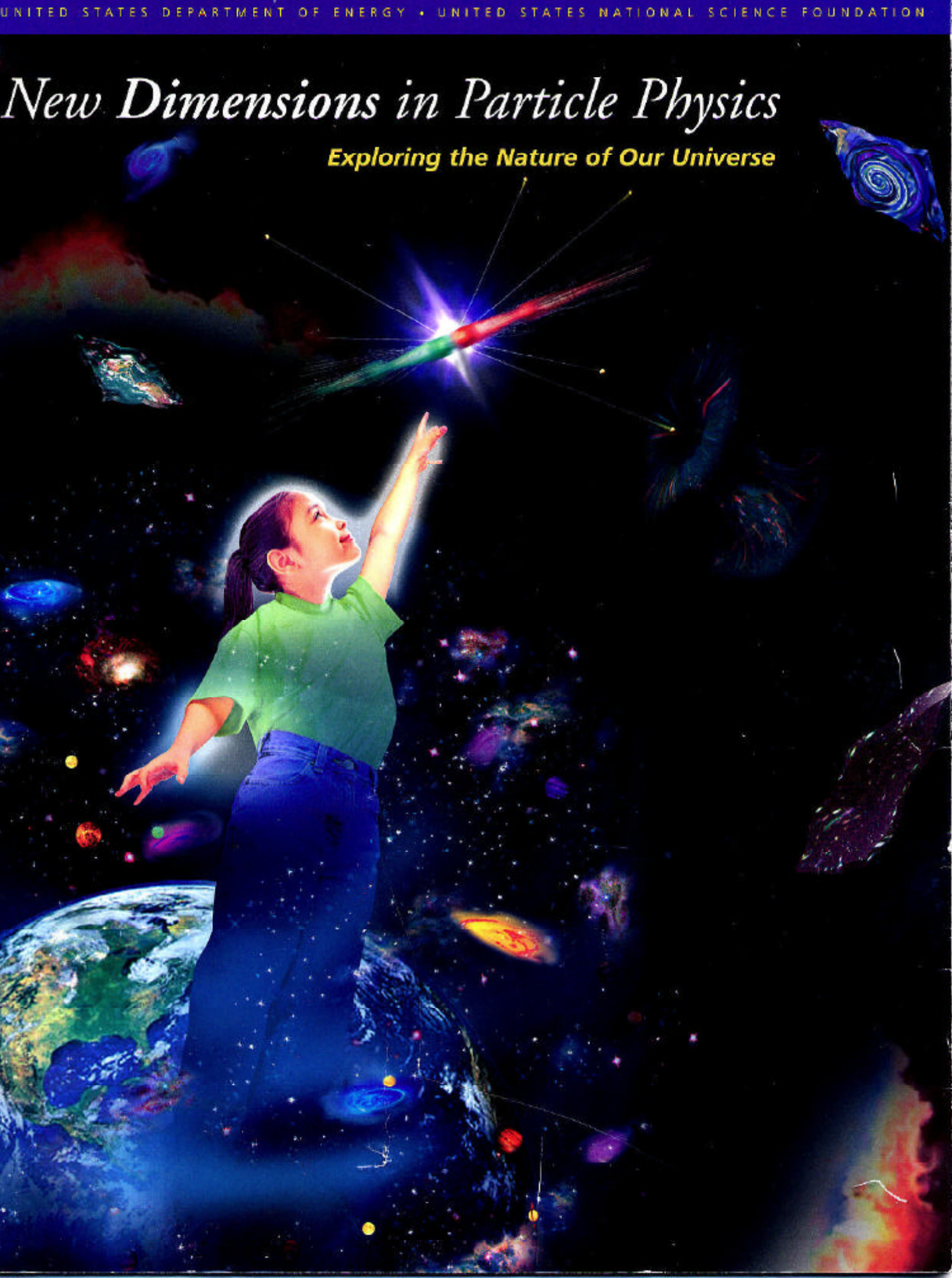
UNITED STATES DEPARTMENT OF ENERGY • UNITED STATES NATIONAL SCIENCE FOUNDATION

New Dimensions in Particle Physics

Exploring the Nature of Our Universe



Experiments in Particle Physics

$$E=mc^2$$

The Origin of Mass

Energy is part of our universe, but why does mass exist? Experiments are currently searching for a particle called a "Higgs boson" that is believed to generate mass. Modern ideas such as supersymmetry and string theory may provide a deeper understanding.

The Path of Discovery

Human curiosity fuels our desire to understand the natural world at ever deeper levels and has led to our greatest achievements in science and technology.

Driven by new puzzles in our understanding of the physical world, particle physicists are following paths to new wonders and startling discoveries. Steps along the path include experiments using everything from supersensitive devices on a laboratory tabletop to giant particle accelerators.

The interactions of fundamental particles such as electrons, quarks, and neutrinos, determine the ultimate fate of the universe and the structure of space itself.

Unification of the Fundamental Forces

Since Einstein's time, we have sought a theory that unifies the forces of Nature. At last we may be close to a theory joining gravity to the strong force that binds the nucleus, the electromagnetic force that holds atoms together, and the weak force that produces the kind of radioactivity used in dating old artifacts with Carbon-14.

New Forces of Nature

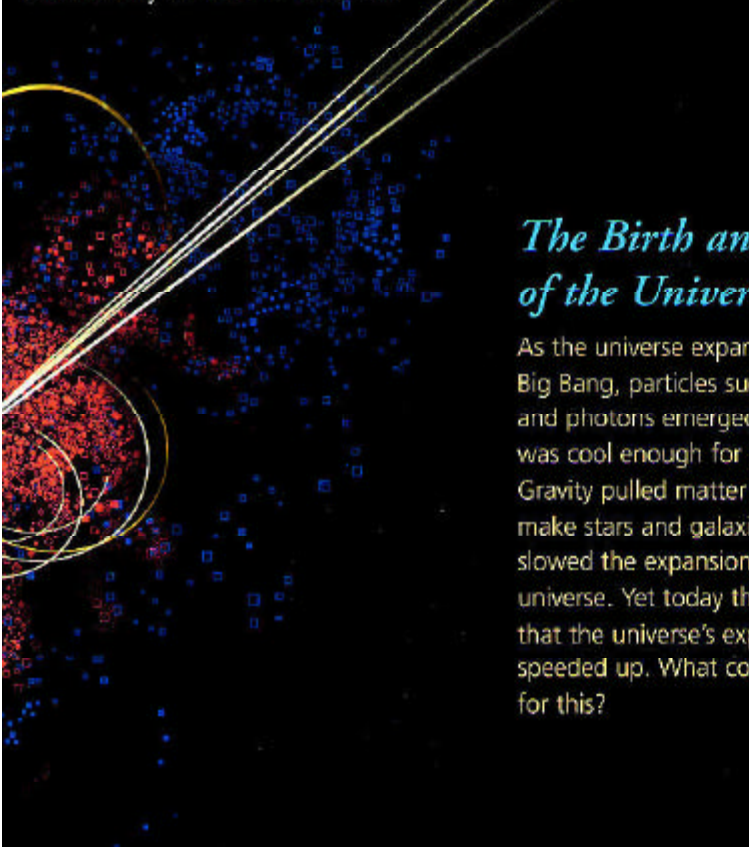
Four fundamental forces are known, but there are reasons to think there may be more forces in nature, including the "anti-gravity" force that seems to be accelerating the expansion of the universe.

Explore Fundamental Issues

Hidden Dimensions of Space

We're all familiar with the three-dimensions of space, but strange as it may seem, there may be additional dimensions we just cannot see. Evidence for hidden dimensions may soon appear in experiments, perhaps in particle collisions like the one below. Hypothesizing extra dimensions helps us understand an otherwise puzzling collection of facts about nature.

Although this is only one of the fascinating questions facing particle physics in the new millennium, we use it on the inside pages to illustrate how particle physics is done and what it may be able to show us.

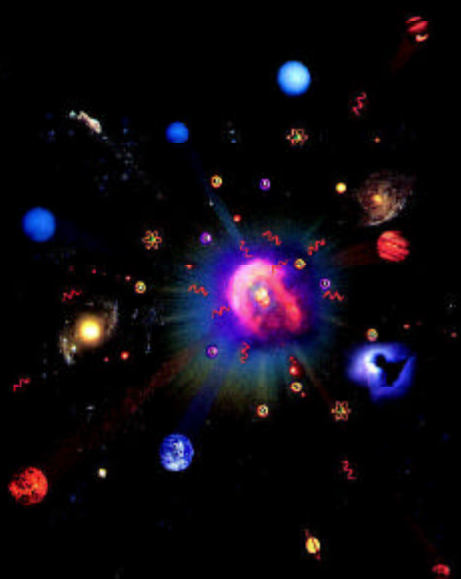


The Missing Antimatter

Matter and antimatter were created in the Big Bang. Why do we now see only matter except for the tiny amounts of antimatter we make in the lab and observe in cosmic rays? When matter and antimatter meet, they annihilate into pure energy.

The Birth and Fate of the Universe

As the universe expanded after the Big Bang, particles such as quarks and photons emerged. Eventually it was cool enough for atoms to form. Gravity pulled matter together to make stars and galaxies. Gravity slowed the expansion of the whole universe. Yet today there is evidence that the universe's expansion has speeded up. What could account for this?



The Nature of Dark Matter and Dark Energy

Astrophysical observations of galaxies and of distant supernovae seem to indicate that much of our universe is dominated by forms of matter and energy unlike anything we have previously seen. Ultra-sensitive experiments attempting to directly detect this dark matter in the laboratory are presently underway.

Challenging our Understanding of Gravity

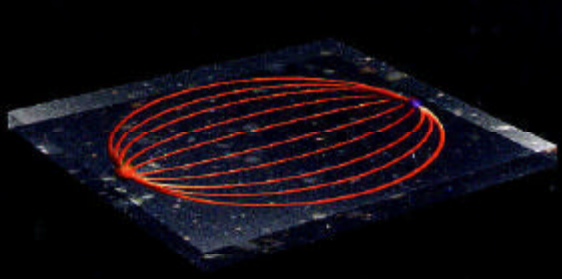
Tabletop Experiments

Some paradoxes of particle physics can be investigated in surprisingly direct ways. Measuring the force of gravity extremely carefully with a tabletop apparatus could reveal the existence of hidden dimensions.

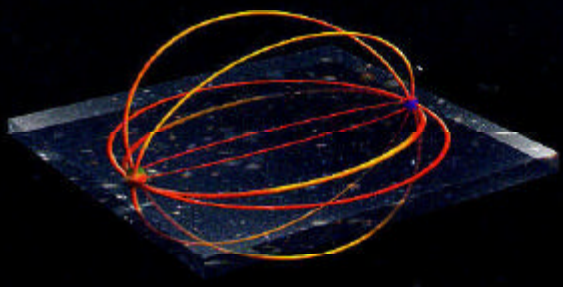
The astonishing possibility is that, at very short distances, gravity may no longer follow Newton's Law (force of gravity varies inversely with distance squared). The actual strength of gravity at less than 1/32 inch (0.8 mm) is being tested using exquisitely sensitive instruments, such as the precision torsion pendulum at the left. A deviation from Newton's Law would be evidence for hidden dimensions.

Gravity and Hidden Dimensions?

Gravity is so weak that a tiny magnet can hold up a paper clip against the gravity of the entire Earth. Perhaps gravity is weak because its effect is spread out over more than three space dimensions, while stronger forces like magnetism are confined to just the three dimensions we perceive. Notice that the field lines below are more spread out in three dimensions than in two dimensions. The same would be true comparing four dimensions to three dimensions.

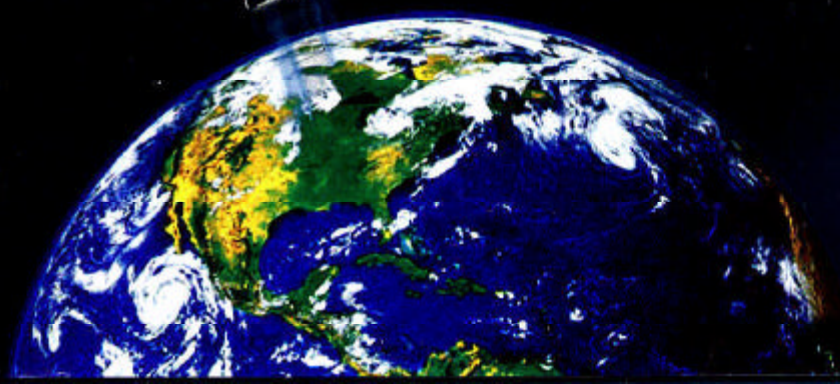


ELECTROMAGNETISM?



GRAVITY?

A tiny magnet exerts greater force than Earth's gravity.



General relativity tells us that gravity warps all of space and is therefore sensitive to all the dimensions of space.

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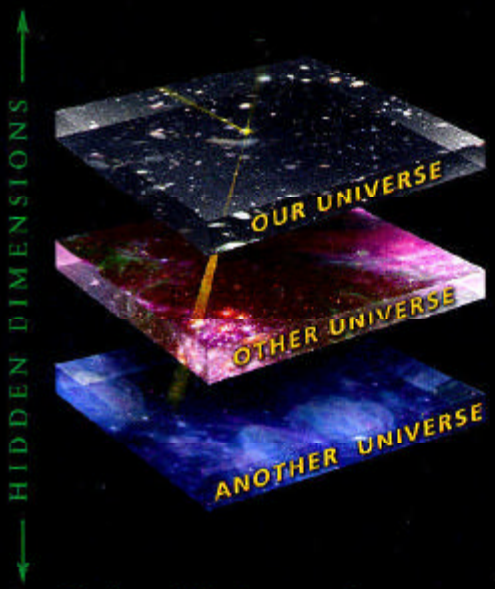
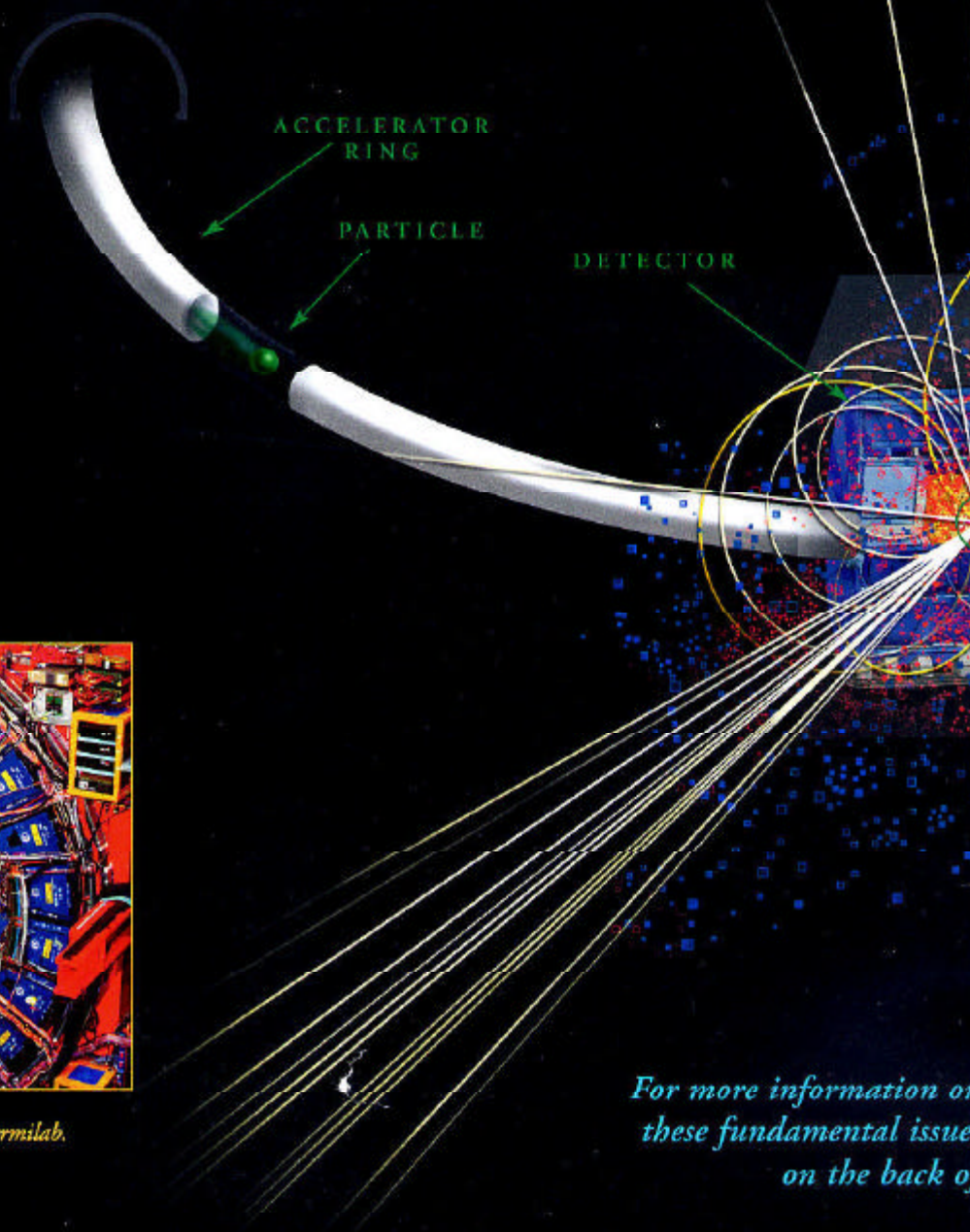


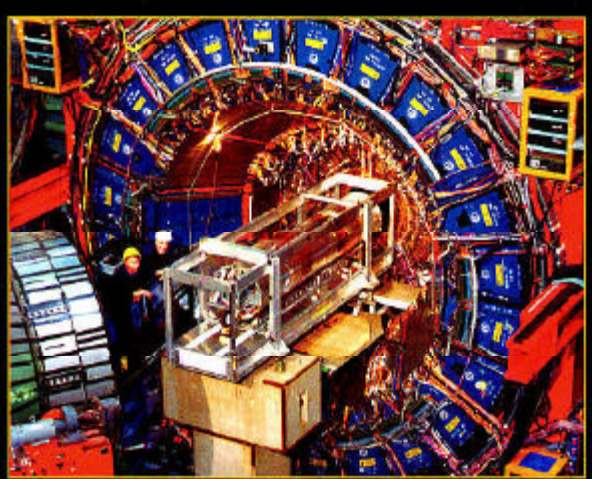
Other Universes?

Our three-dimensional universe may be only one of many 3D universes. These universes may lie within extra (hidden) dimensions. To illustrate this, we show 2D universes in a space with a hidden 3rd dimension. Because of this 2D analogy, these parallel universes are sometimes called "branes," short for membranes. If gravitons (carrier particles of the gravitational force) can travel through other dimensions, they may be putting us in touch with other universes!

Accelerator

Evidence for hidden dimensions migh
Most collisions have a balance of partic
momentum conservation). However, i
be the case. An energetic graviton hea
hidden dimensions. This would cause
more particles headed left than right.
an altogether different three-dimensio





The inner workings of the CDF detector at Fermilab.

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Experiments

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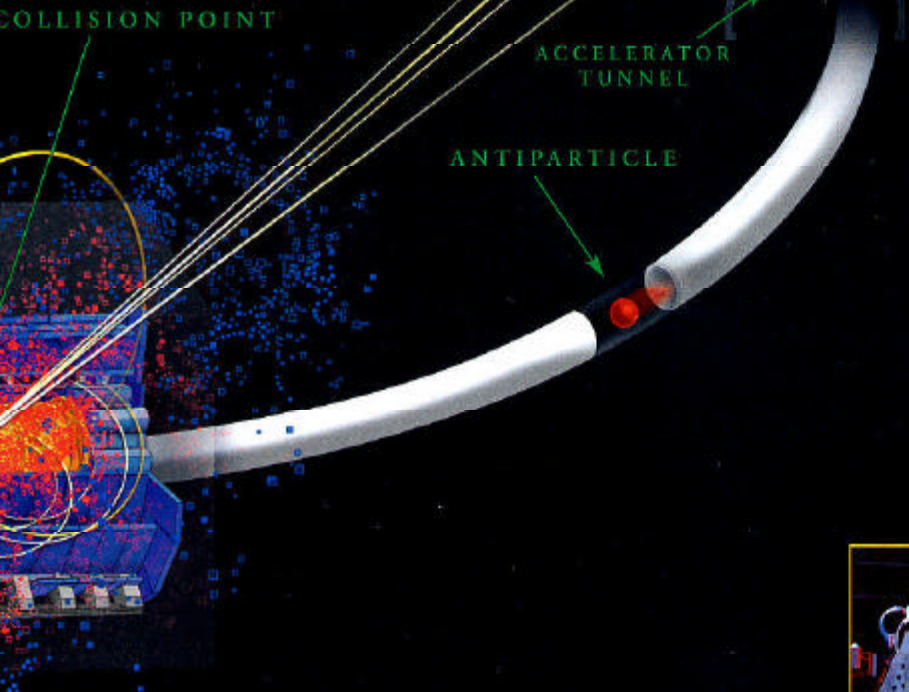
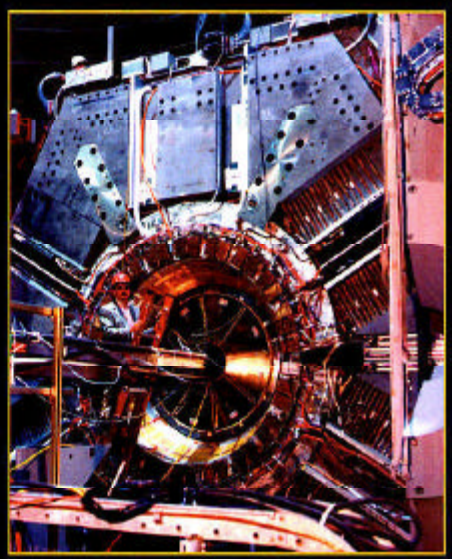
disappear from the detector, leaving
escaped graviton might find itself in
niverse.



Mini Black Holes

Microscopic black holes might be produced in particle collisions that occur when very-high-energy cosmic rays hit particles in our atmosphere. These mini-black-holes would decay into ordinary particles in a tiny fraction of a second and would be very difficult to observe in our atmosphere. However, in powerful accelerators now under construction, we may be able to study these decays in laboratory collisions and show that they came from mini-black-holes.



The calorimeter of the BaBar detector at the Stanford Linear Accelerator Center (SLAC). This end view shows some of the concentric layers used to track particles.

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is brochure.

Seeking Signs of Other Universes

Astrophysical Observations

Through their gravitational pull, universes in other dimensions may have influenced the formation of our universe.

The Impact of Particle Physics

Invention of the World-Wide Web

The World-Wide Web was invented at a particle physics laboratory (CERN) to enable large world-wide collaborations. To see what particle physicists have done with their invention and to learn much more about particle physics, look at these websites:

- *http://ParticleAdventure.org*
- *http://HiddenDimensions.org*
- *http://particleadventure.org/otherlothersites.html*

Educational Programs

Programs for students, teachers and the public at 100 universities and laboratories are described in a 200-page brochure entitled: Particle Physics: *Education & Outreach 2001*. You may request it and also see it at: http://www-ed.fnal.gov/hep/home.html

Particle Physics, Medicine and High-Tech

Medical imaging has been a vital outcome of research such as that in particle physics. Even antimatter has become a tool for medicine. Using positrons (the antiparticle of the electron), Positron Emission Tomography (PET) watches the way cells "eat" substances such as sugar. Cancer cells have a higher metabolism than normal, healthy cells. This enables the PET scanner to identify areas where cancer cells might be present.

The need to analyze enormous amounts of data at institutions around the world has stimulated information technology in new directions with broad future applications (see for example http://www.griphyn.org/info/index.html).

Particle physicists at 160 US universities and laboratories train students to examine problems analytically and quantitatively. The students' skills make them invaluable to medicine, financial institutions, high-tech firms, government, and research institutions.

For more information, contact:
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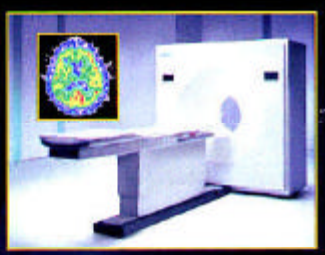

Particle Physics Research

Websites of Major American Particle Physics Labs

- Brookhaven *www.bnl.gov*
- Cornell *www.lns.cornell.edu*
- Fermilab *www.fnal.gov*
- LIGO *www.ligo.caltech.edu*
- SLAC *www.slac.stanford.edu*

International Collaboration

U.S. physicists are playing a major role at the world's most powerful accelerator, the Large Hadron Collider, under construction at CERN (http://www.cern.ch/). They participate in other international experiments in Antarctica, Asia, Europe, North and South America (http://www.slac.stanford.edu/spires/experiments/online_exp.shtml).

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